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Mass-mortality of Guillemots (*Uria aalge*) in the Gulf of Alaska in 1993

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During the first six months of 1993, about 3500 dead and moribund guillemots (*Uria aalge*) were observed throughout the northern Gulf of Alaska coast (*ca* 1800 km range). Mortality peaked during March. Highest numbers were observed in western Prince William Sound and along the south coast of the Kenai Peninsula. Large flocks of live guillemots gathered in nearshore waters, in contrast to most winters when guillemots reside offshore. Most guillemots recovered were extremely emaciated (*ca* 60% of normal weight) and sub-adult (80%). Based on carcass deposition and persistence experiments, we calculate that about 10 900 birds eventually came ashore on beaches that were surveyed. Even if most birds killed made it to shore, only a fraction of beaches in the Gulf of Alaska were surveyed and we estimate that a minimum total of 120 000 guillemots died. Results of other investigations on potential causes of mortality (biotoxins, pathogens, parasites, metals, etc.) were either negative or inconclusive, and necropsies lead us to believe that starvation was the proximate cause of death. Reduced food availability could have been related to anomalous sea conditions found during the prolonged 1990–1995 El Niño-Southern Oscillation event. Published by Elsevier Science Ltd

Mass-mortality of seabirds occurs regularly in both the north Pacific and Atlantic oceans (Tuck, 1961; Bourne, 1976; Harris, 1984), occasionally resulting in the beaching of hundreds or thousands of carcasses. Alcids are often represented in such large-scale die-offs or 'wrecks' (Bourne, 1976). In particular, wrecks of guillemots (*Uria* spp.) have been documented many times during this century (Fleming, 1905; McKernan and Scheffer, 1942; Murie, 1959; Tuck, 1961; Bodle, 1969; Holdgate, 1971; Bailey and Davenport, 1972; Lloyd *et al.*, 1974; Scott *et al.*, 1975; Bourne, 1976; Underwood and Stowe, 1984; Bodkin and Jameson, 1991).

Wrecks may result from acute mortality owing to starvation, diseases, biotoxins or environmental contaminants, but assessing the relative importance of these factors in mortality events is difficult (Lloyd *et al.*, 1974; Scott *et al.*, 1975; Bourne, 1976; Piatt *et al.*, 1990, 1991). In the absence of obvious pathologies, mass-mortality is often ascribed to starvation, which may result from unusually severe weather that hampers foraging (Tuck, 1961; Bailey and Davenport, 1972; Simons, 1985), changes in distribution or abundance of prey (Blake, 1984; Harris, 1984; Hope Jones *et al.*, 1984a,b), anomalous oceanographic conditions (Nysewander and Trapp, 1984; Lobkov, 1986; Hatch, 1987; Bodkin and Jameson, 1991), or some combination of these (Underwood and Stowe, 1984; Piatt and Anderson, 1996).

Diagnoses of starvation are often accompanied by speculation on the effects of sub-lethal pollutant burdens found in wrecked carcasses (Holdgate, 1971; Hope Jones *et al.*, 1984a; Osborn *et al.*, 1984). It is usually difficult to prove (or disprove) that wrecks are entirely 'natural' events because we know so little about changing food resources available to seabirds, the physiology of starvation and the normal environmental contaminant and biotoxin loads borne by seabirds. More complete studies of wrecks are needed to assess the extent to which chronic and point-source pollution affect populations relative to natural mortality factors.

In this report, we describe a wreck of guillemots (*U. aalge*) that occurred during late winter and early spring of 1993 in the northern Gulf of Alaska. We present data on the distribution and number of dead guillemots observed, the duration of the wreck and the physical condition of recovered birds. Using experimental data on the deposition and persistence of beached guillemot carcasses (Van Pelt and Piatt, 1995) and additional assumptions, we speculate on the magnitude of total mortality. Finally, we discuss some possible proximate and ultimate causes of the wreck.

Methods

Reports of dead and dying guillemots were obtained from many sources; most from biologists working in the field, but about 15% were from fishermen or other coastal workers who reported their observations to regional wildlife offices. Most reports specified the location and number of dead or moribund guillemots found. Some anecdotal reports of 'a few', 'dozens' or 'hundreds' of dead birds were received. For these we

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assumed that at least 1, 10 or 100 birds, respectively, were found dead. For our analysis, we tallied the minimum number of birds reported and mapped their distribution. Observations were made on beaches, at sea or from the air. Moribund birds were included in the tally of dead birds.

Most guillemots were recorded on ground-based beach surveys conducted by the US Fish and Wildlife Service, National Park Service and National Biological Service, 16 February–24 June 1993. Aerial surveys for dead guillemots on beaches were flown over Kenai Fjords National Park on 19 February and 13 March, along the outer Gulf of Alaska coast from Cape Spencer to Yakutat on 16 February, and over Sitka Sound on 20 February. Aerial surveys accounted for 12% of the carcass total.

To assess the timing of peak mortality, one beach in Resurrection Bay near the town of Seward (60°05′ N, 149°25′ W) was searched at 1–4 day intervals, from 16 February–18 March. Fresh guillemot carcasses were tallied and their toe-nails clipped to avoid re-counting on later surveys. Van Pelt and Piatt (1995) conducted systematic surveys to assess carcass deposition and persistence, 20 March–28 June, on this same beach plus another, and the results are used here to describe deposition chronology following the mortality peak.

Dead and moribund guillemots were collected from southeast Alaska ($n=5$), Valdez Harbor ($n=10$), Resurrection Bay/Kenai Fjords ($n=78$) and Anchorage ($n=1$) for necropsies to determine weight, condition, sex, age, stomach contents and possible gross signs of the cause of mortality. Birds were weighed to the nearest 10 g using a Pesola® scale. On dissection, the abdominal subcutaneous and mesenteric fat was ranked on a four-point scale from 0 (no fat visible) to 3 (thick fat deposits). Age was determined by the presence (immature) or absence (adult) of cloacal bursa (Hope Jones *et al.*, 1984b; Camphuysen and van Franeker, 1992). Weights were obtained from an additional 30 fresh carcasses from Seward. Tissues and stomachs were taken from subsamples of collected specimens to check for potential pathogens and contaminants (L. Creekmore, C. Meteyer, C. Martin and R. Britton, unpubl. data).

Results

Distribution, magnitude and timing of mortality

Two moribund guillemots were found in mid-January near the town of Kenai (60°33′ N, 151°19′ W); both were extremely emaciated. Throughout the rest of January and the first two weeks of February, low numbers of dead or dying guillemots were observed in southeast Alaska (Sitka), the northeast Gulf of Alaska (Kayak I.), Anchorage and Kodiak (Fig. 1). During the last two weeks of February, higher numbers were reported from the Kenai Peninsula, Prince William Sound, Cook Inlet and Kodiak Island. Throughout March, we received numerous reports of dead or dying guillemots along coasts of the Kenai Peninsula, lower Cook Inlet and Kodiak Island. The largest numbers of dying guillemots were observed in Resurrection Bay and in adjacent bays to the west (Kenai Fjords National Park). In total, 3504 dead or moribund guillemots were recorded (111 from Sitka to Cordova; 745 from Cordova to Resurrection Bay; 2557 from Resurrection

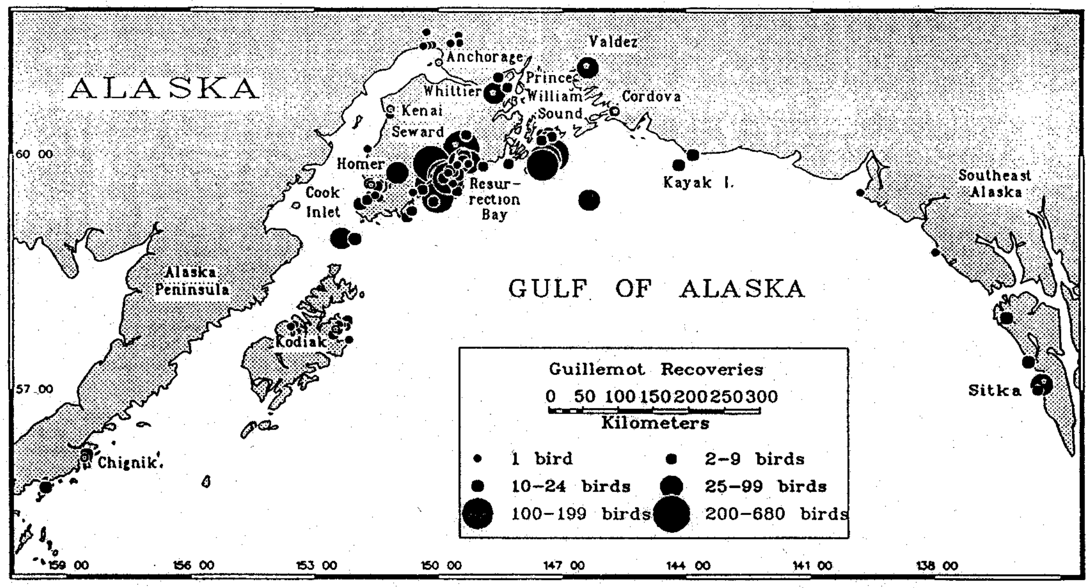

Fig. 1 Distribution and number of dead or moribund guillemots observed in the northern Gulf of Alaska, January–May, 1993.

Bay to Cook Inlet; 91 from Cook Inlet to Chignik). Anecdotal reports of 100s and 1000s of dead guillemots floating far at sea were received, but are not included in the tally of dead. Only a few carcasses (<20, mostly procellarids) of other species were found in all areas.

Coincident with reports of dead guillemots were sightings of large flocks (100s to 1000s) where they are not normally seen in winter, i.e. the inshore waters and harbours near the coastal towns of Sitka, Cordova, Valdez, Whittier, Seward, Homer and Kodiak. Unusual behaviour was observed at all sites. Many guillemots appeared listless and disoriented and were easily approached. Moribund guillemots were observed coming ashore, where they subsequently died. Guillemots were also observed flying inland (up to 30 km) and landing on roads, parking lots, etc., in the vicinity of coastal towns.

Systematic and repeated beach surveys for guillemot carcasses conducted near Seward revealed that mortality peaked around 11 March (Fig. 2).

Physical condition of birds

Most guillemots examined were extremely emaciated, with no subcutaneous or mesenteric fat deposits, and severely reduced pectoral muscle mass. The mean weight (669 g±100 SD, $n=124$) of wrecked guillemots euthanized or collected within a few hours of death was significantly lower (Mann–Whitney U-test; $p<0.0001$) than the mean weight (1069 g±101 SD, $n=181$) of guillemots collected in the Gulf of Alaska during summer (J. Piatt, unpubl. data; Fig. 3). All birds were in winter (basic) plumage, although a few exhibited the beginnings of feather moult on the neck.

For 82 of the 124 weighed birds, necropsies to determine sex, age and gross abnormalities were performed. The sex ratio was 1:1, and 66 (80%) birds were immature. Pulmonary oedema was observed in 75% of carcasses, and focal haemorrhaging of dilated, flaccid intestines was observed in 35% of carcasses.

Of 46 stomachs examined, 29 (63%) were completely empty. The remainder had small fragments of fish otoliths or vertebrae (Clupeidae and Gadidae) in the ventriculus. Intestinal parasites (tapeworms or nematodes) were found in about 50% of the stomachs. No unusually heavy infestations were observed.

Estimating total mortality

Estimating total mortality from carcasses recovered on beaches is difficult (Ford *et al.*, 1987; Piatt and Ford, 1996) because: *1.* an unknown proportion of birds that die at sea wash ashore; *2.* beach surveys rarely cover the entire area of carcass deposition, and *3.* only a fraction of beachcast carcasses are observed because scavenging and physical processes remove or hide carcasses over time. In this case, the first and second factors may only be approximated, but we conducted experiments (Van Pelt and Piatt, 1995) that allow us to calculate the cumulative number of guillemot carcasses deposited on surveyed beaches over the duration of this wreck.

Most beaches in the wreck area were visited only once by investigators. Thus, many birds deposited before the visit had already disappeared, and birds deposited after the visit were not recorded by observers. Based on a three-month study of the deposition and persistence of beachcast carcasses on two beaches in Resurrection Bay (Van Pelt and Piatt, 1995), we derived an equation which relates the number of carcasses found on any given survey date and beach to the cumulative number of carcasses that should have been deposited on that beach throughout

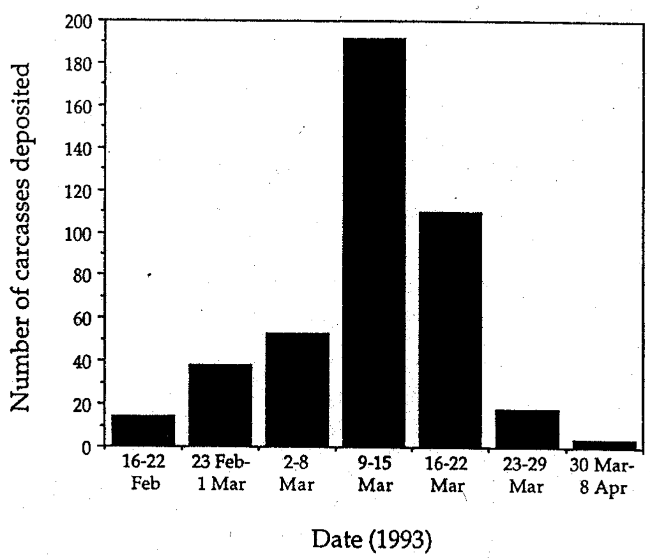

Fig. 2 Numbers of fresh (<2 days since death) guillemot carcasses found on Seward beaches, by weekly period.

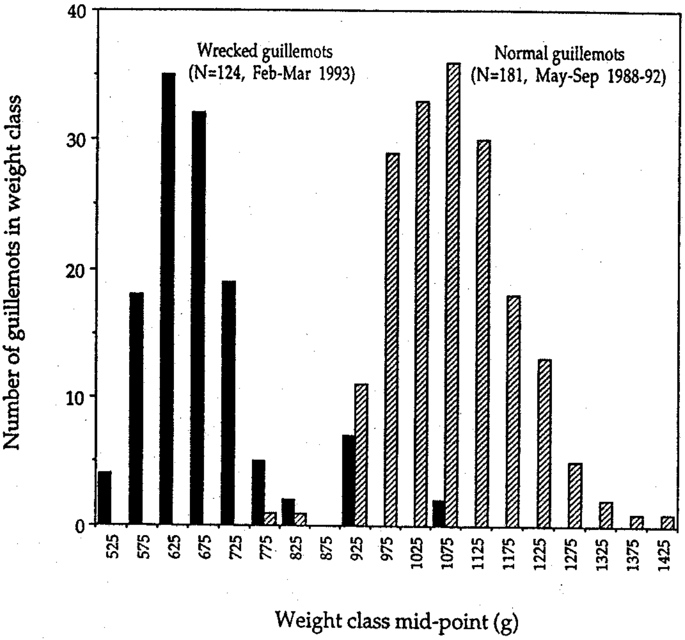

Fig. 3 Weight (g) distributions of guillemots recovered during the wreck and normal guillemots collected at a variety of sites in the Gulf of Alaska and Aleutian Islands.

the wreck period. Assuming the mortality rate peaked on 11 March (Fig. 2) and applying the correction factor to all beach survey reports, our best estimate is that about 10 900 guillemots were actually deposited on beaches that were surveyed.

Discussion

Magnitude and proximate cause of the mortality

To estimate total mortality from the observed mortality, we must account for those birds that sank at sea or were carried offshore, and for those birds that were deposited on beaches that were not surveyed. From a variety of carcass drift experiments conducted at other times and places (Piatt and Ford, 1996), one could predict that only about 15% of guillemots dying at sea ever drifted to shore. It was apparent in this wreck, however, that many guillemots did not passively drift to shore, but instead actively concentrated in protected waters, sometimes even walking ashore to die. Therefore, we estimate conservatively that 90% of dead and dying birds reached shore.

Shoreline from the outer coast of southeast Alaska to mid-way down the Alaska Peninsula (Fig. 1), including Prince William Sound, Cook Inlet and Kodiak Island, comprises over 18 000 linear kilometers. Only a fraction (< 1%) of all possible beaches were checked throughout this vast area in which mortality was observed. Not surprisingly, most records came from close proximity to coastal communities. Unfortunately, most reports did not include estimates of total beach area surveyed. Mortality was concentrated along the relatively populous Kenai Peninsula, and we estimate that about 5% of this shoreline (1990 km) was examined. However, only about half (51%) of this shoreline consists of gravel and sand beaches, estuaries and sheltered rocky shores (ECI, 1991) upon which most carcasses were found. The remainder of the coast is exposed rocky beaches and cliffs (ECI, 1991). For purposes of extrapolation, we therefore estimate conservatively that 10% of suitable shoreline upon which most carcasses were deposited was surveyed and thus, we speculate that a minimum of about 120 000 [10 900/(0.9×0.1)] guillemots died over the duration of this wreck.

The magnitude of this wreck does not appear unusual for areas with large seabird populations. In the Atlantic Ocean, 15 000 guillemots died *en masse* in the Irish Sea in Autumn 1969 (Holdgate, 1971; Bourne, 1976) and five years later an estimated 17 600 seabirds (60% guillemots) died in the same area (Lloyd *et al.*, 1974). In February of 1983, 30 000 auks (10 000 guillemots) washed ashore from the North Sea following a series of storms (Harris and Wanless, 1984). An estimated 50 000 seabirds (mostly guillemots) were reported killed in a North Sea wreck in February 1994 (Tasker, 1994). In the Pacific Ocean, Scott *et al.* (1975) estimated (based on recovery of 313 carcasses) that 51 100 guillemots died along the Oregon coast in July and August of 1969. About 8500 guillemots were counted on beaches along the Alaska Peninsula in April of 1970, leading to an estimate of 100 000 guillemots killed (Bailey and Davenport, 1972).

All indications are that the proximate cause of mortality in this wreck was starvation. Emaciation to about 60% of normal weight has often been noted in wrecked guillemots (Lloyd *et al.*, 1974; Scott *et al.*, 1975; Bourne, 1976; Hope Jones *et al.*, 1984a,b; Camphuysen, 1989) and appears to be the limit of weight-loss that can be tolerated by guillemots before death occurs. Pulmonary oedema and haemorrhaging of the intestines are frequently observed in wrecked guillemots, and may be symptomatic of starvation (Bailey and Davenport, 1972; Lloyd *et al.*, 1974; Scott *et al.*, 1975). Mass-mortality over a short time period, weak and dying birds concentrating in protected waters, and the occurrence of disoriented guillemots far inland, are all characteristic of guillemot wrecks attributed to starvation (Murie, 1959; Tuck, 1961; Bailey and Davenport, 1972; Lloyd *et al.*, 1974; Bourne, 1976).

Possible ultimate causes of mortality

The unusual observations of large aggregations of live guillemots in sheltered nearshore waters during this wreck suggest that adequate food supplies were not present on their normal offshore feeding grounds. Because of frequent storms, winter is likely to be a difficult time to find suitable prey concentrations, even in normal years (Blake, 1984), and severe weather has often been suggested as an ultimate cause of mortality (Bailey and Davenport, 1972; Simons, 1985). However, the winter of 1992–1993 in the Gulf of Alaska was relatively mild, as measured by Trenberth's North Pacific index of the Aleutian low pressure system (Trenberth and Hurrell, 1994). Moreover, there were no extraordinary storms around the time of peak mortality.

Food supplies may have been affected by an unusually prolonged 1990–1995 El Niño-Southern Oscillation (ENSO) event, whose five-year duration is unprecedented in the climate record of the past century (Trenberth and Hoar, 1995). Anomalously warm water temperatures (+1 to 4°C) persisted in the northeast Pacific from California to Alaska during the winter of 1992–1993 and spring of 1993. Effects of this ENSO on seabirds were far-reaching. Seabird breeding was delayed and breeding success was extremely poor at the Farallon Islands, California in 1992 and 1993 (Sydeman *et al.*, 1994). Large die-offs as well as reproductive failures of guillemots, rhinoceros auklets (*Cerorhinca monocerata*) and Cassin's auklets (*Ptychoramphus aleuticus*) were recorded in British Columbia, Washington and Oregon (Burger, 1993; Lowe, 1993). Tufted puffin (*Fratercula cirrhata*) foraging and breeding success was also greatly reduced in the Gulf of Alaska in 1993 (Bailey *et al.*, 1995). In summary, effects of the 1992–1993 ENSO were similar in magnitude to those of the ENSO of 1982–1983, which caused widespread breeding failure and mortality of seabirds from California to Alaska (Nysewander and Trapp, 1984; Hatch, 1987; Ainley and Boekelheide, 1990; Bodkin and Jameson, 1991). The mechanism by which ENSO events affect forage fish and therefore higher predators such as seabirds remains unclear (Bailey *et al.*, 1995). In Alaska, warm water temperatures may reduce availability of forage fish to seabirds by causing direct mortality of forage species, reducing recruitment, or, most likely, by causing a re-distribution of forage fish to deeper, cooler waters (Bailey *et al.*, 1995).

There was no conclusive evidence that either biotoxins or environmental contaminants were a primary cause of mass-mortality. Trace amounts of saxitoxin, a source of paralytic shellfish poisoning, were found in stomach contents of two guillemots, and also in euphausiids (*Thysanoessa* spp.) that had washed up on a beach in Resurrection Bay (C. Martin, unpubl. data), but such findings could represent normal background levels. If biotoxins were a primary cause of mortality, more species of marine birds should have been affected (e.g. McKernan and Scheffer, 1942; Bodle, 1969; Armstrong *et al.*, 1978). Metal concentrations in wrecked guillemots were similar to those found in previous studies of guillemots collected from healthy populations (see Table 1). However, birds that are weakened from food stress may become more susceptible to deleterious effects from normal concentrations of biotoxins or environmental contaminants.

Effects on populations

The total population of guillemots in the northern Gulf of Alaska is about 1.8 million individuals (Piatt and Anderson, 1996). The wreck's impact on this population is difficult to predict, but may be similar in scale to the effects of mortality following the T/V *Exxon Valdez* oil spill in which an estimated 185 000 guillemots were killed (Piatt *et al.*, 1990; Piatt and Ford, 1996). Effects of *Exxon Valdez* mortality on guillemot populations were difficult to detect (Piatt and Anderson, 1996), and it is unlikely that effects of this wreck will be detectable either, especially since 80% of the guillemots examined were non-breeding subadults and mortality may have been spread between guillemots from many different colonies. In an analogous situation, the wreck of 30 000 auks in the North Sea in February 1983 (47% subadult guillemots) had no detectable effect on numbers, breeding success, or phenology of auks breeding on the Isle of May in the following summer (although adult survival rates were significantly lower; Harris and Wanless, 1984). However, a major difference between these events is that auk populations were expanding at the time of the North Sea wreck, whereas this wreck followed on the heels of an unfavourable decade for guillemots in the northern Gulf of Alaska (Piatt and Anderson, 1996).

Documentation of this wreck relied on the generous efforts of many volunteers, who are too numerous to list here completely. We are grateful to them all. In particular, we thank K. Bell, R. Britton, G. V. Byrd, L. Creekmore, P. Dysan, G. Esslinger, S. Hatch, D. Irons, S. Kendall, C. Lensink, N. Naslund, D. Roseneau, P. Seiser, L. Slater

TABLE 1

Metal concentrations (expressed as ppm in dry and wet weight) in guillemots killed in the 1993 Gulf of Alaska wreck, with comparisons to other studies.

		Dry weight			Wet weight		
Element	Tissue	Mean±SD	Range	Comparative range[a] (source[b])	Mean±SD	Range	Comparative range[a] (source[b])
Cd	Kidney	13.7±19.9	2.62–53.9	1.56–46.7 (1,2)	2.85±4.02	0.61–11.0	2.27–16.0 (3,4)
Cd	Liver	4.46±4.69	0.52–13.6	1.09–5.51 (1,2)	1.12±1.12	0.16–3.30	0.35–3.90 (3,4)
Hg	Kidney	1.08±0.30	0.55–1.31	0.84–3.93 (1,2)	0.23±0.05	0.13–0.26	0.18±0.04 (3)
Hg	Liver	1.80±1.32	0.77–4.41	0.87–3.66 (1,2)	0.46±0.32	0.23–1.11	0.22±0.05 (3)
Se	Kidney	20.1±9.57	13.5–38.4	15:8–43.7 (1)	4.54±2.87	2.99–10.3	—
Se	Liver	12.5±5.77	8.67–23.8	7.05–17.6 (1)	3.40±1.92	2.50–7.25	1.10–2.60 (4)
Cu	Kidney	14.4±8.53	5.62–27.2	—	2.98±1.50	1.30–5.00	3.79–6.90 (3,4)
Cu	Liver	30.8±11.3	16.7–43.8	—	8.18±3.14	4.70–13.0	5.4–8.20 (3,4)
Fe	Kidney	481±215	279–786	—	110±63.7	57.0–2.10	188±35.3 (3)
Fe	Liver	1552±506	1028–2188	—	418±156	250–650	282±79.3 (3)
Mn	Kidney	n.d.	n.d.	—	n.d.	n.d.	1.31±0.11 (3)
Mn	Liver	11.5±3.24	6.19–15.8	—	3.10±0.98	1.50–4.10	2.75±0.43 (3)

[a]Comparative concentrations are means or ranges determined in apparently healthy guillemots (*Uria* spp.) collected at sea in both the North Pacific and Atlantic oceans. For single means, ±standard deviation is shown.
[b]Sources: (1) Wenzel and Gabrielsen, 1995; (2) Stewart *et al.*, 1994; (3) Honda *et al.*, 1990; (4) Norheim, 1987.
n.d.: Not detected.
Analyses were contracted through the USFWS-Patuxent Analytical Control Facility (catalog no. 7010014).

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